COPY FOR MR. J. ALLAN ROSS

HYDRO-ELECTRIC INQUIRY COMMISSION

ENGINEERING DATA

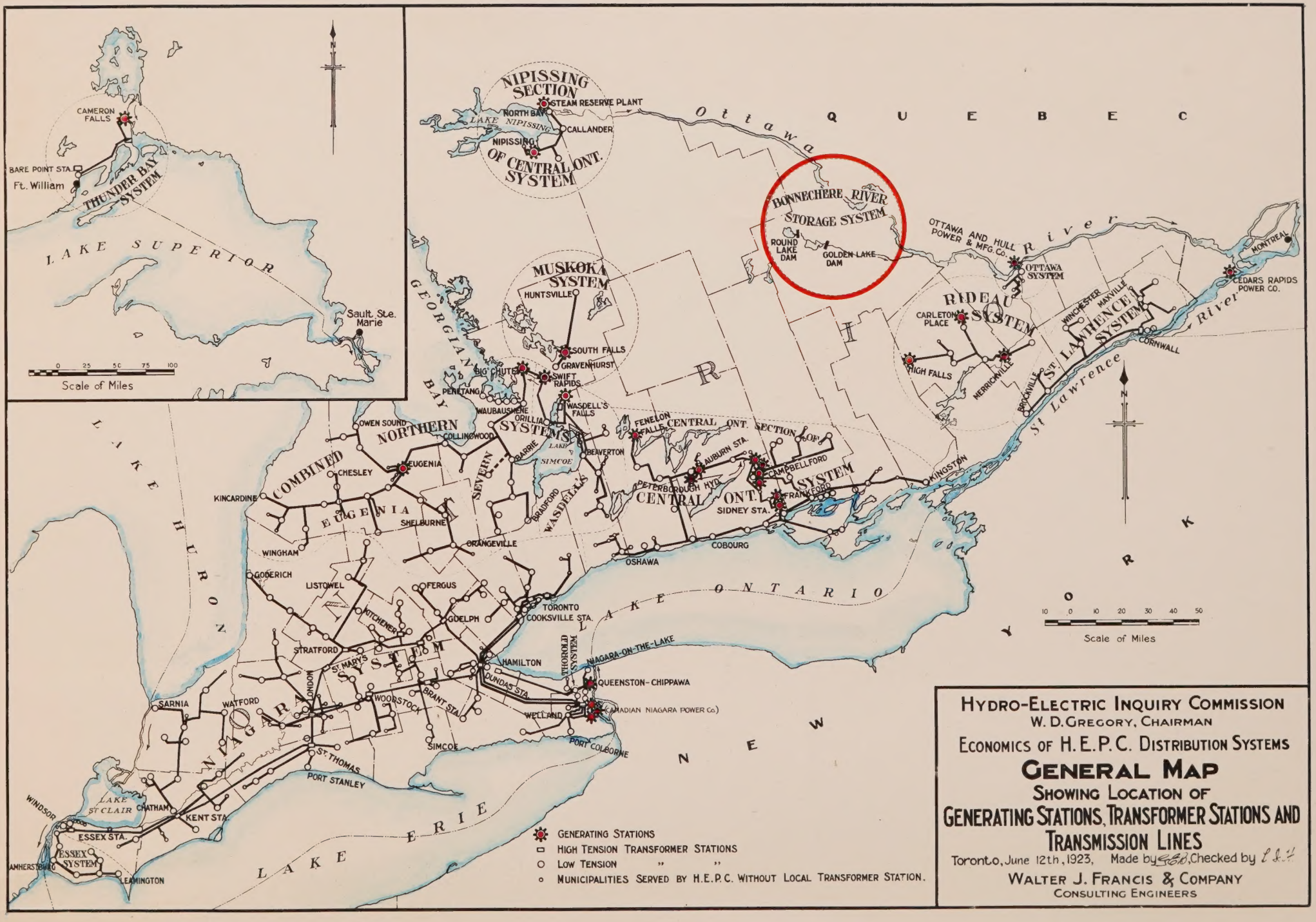
ECONOMICS OF H. E. P. C. DISTRIBUTION SYSTEMS

STUDY OF BONNECHERE RIVER STORAGE SYSTEM

WALTER J. FRANCIS & COMPANY

CONSULTING ENGINEERS

BONNECHERE RIVER STORAGE SYSTEM


HYDRO-ELECTRIC INQUIRY COMMISSION
W. D. GREGORY, CHAIRMAN
ECONOMICS OF H.E.P.C. DISTRIBUTION SYSTEMS
GENERAL MAP
SHOWING LOCATION OF
GENERATING STATIONS, TRANSFORMER STATIONS AND TRANSMISSION LINES
Toronto, June 12th, 1923, Made by G.S.O., Checked by L.S.F.
WALTER J. FRANCIS & COMPANY
CONSULTING ENGINEERS
GENERATING STATIONS
HIGH TENSION TRANSFORMER STATIONS
LOW TENSION " "
MUNICIPALITIES SERVED BY H.E.P.C. WITHOUT LOCAL TRANSFORMER STATION.
Scale of Miles
THUNDER BAY SYSTEM
CAMERON FALLS
BARE POINT STA.
Ft. William
LAKE SUPERIOR
Sault Ste. Marie
NIPISSING SECTION OF CENTRAL ONT. SYSTEM
STEAM RESERVE PLANT
NORTH BAY
CALLANDER
NIPISSING
LAKE NIPISSING
MUSKOKA SYSTEM
HUNTSVILLE
SOUTH FALLS
GRAVENHURST
BIG CHUTE
SWIFT RAPIDS
WASDELL'S FALLS
PENETANG
WAUBAUSHENE
ORILLIA
BARRIE
LAKE SIMCOE
BEAVERTON
GEORGIAN BAY
NORTHERN SYSTEM
OWEN SOUND
COLLINGWOOD
COMBINED EUGENIA SYSTEM
EUGENIA
CHESLEY
KINCARDINE
SHELBURNE
WINGHAM
GODERICH
LISTOWEL
SEVERN
BRADFORD
WASDELL'S
ORANGEVILLE
FERGUS
GUELPH
KITCHENER
STRATFORD
ST. MARYS
LONDON
NIAGARA SYSTEM
SARNIA
WATFORD
WOODSTOCK
BRANT STA.
SIMCOE
ST. THOMAS
PORT STANLEY
LAKE ST CLAIR
CHATHAM
KENT STA.
WINDSOR
ESSEX STA.
ESSEX SYSTEM
AMHERSTBURG
LEAMINGTON
LAKE HURON
LAKE ERIE
HAMILTON
DUNDAS STA.
THOROLD SYSTEM
WELLAND
PORT COLBORNE
NIAGARA-ON-THE-LAKE
QUEENSTON-CHIPPAWA
(CANADIAN NIAGARA POWER Co.)
LAKE ONTARIO
TORONTO
COOKSVILLE STA.
OSHAWA
COBOURG
CENTRAL ONT. SECTION OF
FENELON FALLS
PETERBOROUGH HYD.
AUBURN STA.
CAMPBELLFORD
FRANKFORD
SIDNEY STA.
KINGSTON
BONNECHERE RIVER STORAGE SYSTEM
ROUND LAKE DAM
GOLDEN LAKE DAM
OTTAWA AND HULL POWER & MFG. Co.
OTTAWA SYSTEM
RIDEAU SYSTEM
CARLETON PLACE
HIGH FALLS
MERRICKVILLE
BROCKVILLE
WINCHESTER
MAXVILLE
ST. LAWRENCE SYSTEM
CORNWALL
CEDARS RAPIDS POWER CO.
MONTREAL
Ottawa River
St Lawrence River
QUEBEC
NEW YORK

WALTER J. FRANCIS & COMPANY.

COPY FOR ENCLOSURE TO Mr. J. Allan Ross.

To face frontispiece.

General Map Showing Location of

Generating Stations, Transformer Stations and Transmission Lines

of the

Hydro-Electric Power Commission of Ontario.

COPY

The area outlined in red shows the

Bonnechere River Storage System.

INDEX TO BONNECHERE RIVER STORAGE SYSTEM

LIST OF ILLUSTRATIONS

BONNECHERE RIVER STORAGE SYSTEM

WALTER J. FRANCIS & COMPANY.

COPY FOR ENCLOSURE TO Mr. J. Allan Ross.

Toronto, Ontario,

June 12th, 1923.

Hydro-Electric Inquiry Commission,
W. D. Gregory, Esq., Chairman,
T O R O N T O, Ontario.

re Studies of Engineering Economics of the
Bonnechere River Storage System of the
Hydro-Electric Power Commission of Ontario

Mr. Chairman and Gentlemen,-

In accordance with the letter to your Commission under date of November 4th, 1922, and your confirmation of the general instructions under date of November 15th, 1922, a study has been made of the engineering economics of the Bonnechere River Storage System owned by the Hydro-Electric Power Commission of Ontario and operated by the Town of Renfrew. The work has been done under the direct personal supervision of Mr. Frederick B. Brown, M. Sc., M.E.I.C., a partner in the firm of Walter J. Francis & Company, in accordance with your instructions.

The subject has been discussed with Mr. Commissioner R. A. Ross in detail, and, generally, with Mr. Bower, the Secretary of your Commission, and constant communication has been maintained with the officials of the Hydro-Electric Power Commission of Ontario.

The reports of Messrs. Price, Waterhouse & Co. have been used as the basis of the financial figures given herein, and reference has been made to the records of the Hydro-Electric Power Commission of Ontario where it was necessary to do so to prepare the figures.

It is understood that it is not within the scope of the instructions to examine into any of the legal aspects of the System nor to discuss any of the Acts of the Legislature relating to it.

The necessary technical data has required considerable preparation as much of it is only available in the operating records of the Hydro-Electric Power Commission of Ontario and in the Water Resources Papers of the Dominion Water Power Branch. The printed reports contain a part, but these have had to be supplemented by interviews with various officials and by searching the voluminous records both at the head office in Toronto and elsewhere.

The general plan under which the report of the studies is presented may be outlined as follows:

(1) A short review of the history and evolution of the System.

(2) A brief physical description of the System.

(3) A brief discussion of the results obtained from storage.

(4) A study of the mass curve for the System.

(5) A discussion of the progressive capital costs.

(6) A discussion of the annual costs.

(7) A brief discussion of the various important points concerning the System.

The report included herewith as pages 3 to 26 inclusive refers in detail to that portion of the activities of the Hydro-Electric Power Commission known as the Bonnechere River Storage System.

The map included as a frontispiece shows the System generally and its geographical relation to all the other Systems operated by the Hydro-Electric

Power Commission of Ontario, and the mass curve shown in two sections as pages 19 and 20 makes it possible to estimate the flow characteristics of the river with various amounts of storage.

BONNECHERE RIVER STORAGE SYSTEM

Frederick B. Brown, M.Sc.

Evolution and Development of the System.

The Bonnechere River Storage System is a water storage system in the basin of the Bonnechere River comprising two storage dams, the first at the foot of Round Lake and the second at the outlet of Golden Lake. These two dams were constructed by the Hydro-Electric Power Commission of Ontario to increase the minimum flow in the Bonnechere River and to improve the supply of water power to the Town of Renfrew, to the Renfrew Paper Company, and to other water power users on the river.

The Town of Renfrew, in Renfrew County, with a population of 5,600 is supplied with electric power, under municipal control, from two hydro-electric plants situated on the Bonnechere River. Station No. 1 was installed in 1911, and an additional turbine and generator were added in 1915, making a total turbine capacity of 800 horse-power, and a total generator capacity of 500 kv-a. or 400 kw. at 80 per cent. power factor. The plant operates under an average head of 37 feet. Station No. 2 was installed in 1901 with one 400 horse-power unit, and a 500 horse-power unit was added in 1907. The total generator capacity in Station No. 2 is 700 kw. This plant was formerly owned by the Renfrew Power Company, and was acquired by the Municipality of Renfrew on September 30th, 1917. It operates under an average head of 35 feet.

[illegible]

Frederick L. Ryan, E.E.

Description and Statement of the Plants.

The Housatonic River Storage System is a water storage system in the basin of the Housatonic River, supplying the storage dams, the first of the two of which was put into service at Stevens Lake. These two dams were constructed by the Housatonic River Development of Boston to increase the minimum flow in the Housatonic River and improve the supply of water power in the Town of Danbury, to the Danbury Water Company, and to other water power users on the river.

The town of Danbury, in Fairfield County, with a population of 8,000 is supplied with electric power, under municipal control, from one hydro-electric plants situated on the Housatonic River. Station No. 1 was installed in 1911, and an additional turbine and generator were added in 1918, making a total turbine capacity of 800 horse-power, and a total generator capacity of 500 kw-a. or 625 kw. at 80 per cent. power factor. The plant operates under an average head of 37 feet. Station No. 2 was installed in 1915 with one 625 horse-power unit, and a 625 horse-power unit was added in 1917. The total generator capacity in Station No. 2 is 1250 kw. This plant is owned by the Danbury Water Company, and was acquired by the Municipality of Danbury on September 20, 1917. It operates under an average head of 25 feet.

At various times the industries in the Town of Renfrew have suffered from shortage of water and shortage of electric power. This condition became acute in the fall and winter of 1908. As Renfrew had no rights on the Bonnechere River, except at its proposed power site, an appeal was made to the Hydro-Electric Power Commission of Ontario for relief by the development of artificial storage at the headwaters of the river. Again in the fall of 1910 the level of the Bonnechere River reached such a low stage that the river was practically useless as a source of power, and for some time such industries in the Town of Renfrew as were not equipped with steam auxiliaries were practically without motive power. The conditions at that time demonstrated conclusively the necessity of providing storage reservoirs to improve the flow characteristics of the river. Negotiations and studies were continued, and in February and March, 1911, a detailed survey of Round Lake was made by the engineers of the Hydro-Electric Power Commission to determine its capacity as a storage reservoir to provide for low water periods in the Bonnechere River.

It is stated that due to the lack of rainfall records in the Bonnechere watershed, it was impossible to estimate the percentage of run-off with certainty. Records at Renfrew extending back to 1882 indicated that the mean annual rainfall at that point was about 25 inches. Records for any other points in the watershed were entirely lacking, but on the height of land in the Algonquin Park region the records showed a mean annual rainfall of 40 to 45 inches. In view of this it seemed reasonable to the engineers to assume 30 inches as the measure of the average distribution of rainfall above Golden Lake Village, and 25 inches for the mean annual rainfall on the remainder of the Bonnechere

watershed. It was also assumed that the Bonnechere River could deliver a run-off of 33.3 per cent. of the annual rainfall.

On January 9th, 1912, an agreement was executed between the Town of Renfrew and the Hydro-Electric Power Commission which provided for the construction of a dam at the outlet of Round Lake. It was agreed that the capital cost of the dam should be borne by the Hydro-Electric Power Commission, while the total annual costs including operation and maintenance costs, and interest and sinking fund payments, were to be paid to the Commission by Renfrew. Provision was made for the operation of the dam by Renfrew at the option and under the control of the Commission so as to protect the interests of the property holders on or about the shores of Round Lake and along the Bonnechere River. No Order-in-Council was passed validating this agreement and the legal status of the work has not been discussed herein, but apparently no opposition was offered by the riparian owners at the time. In 1911 the first municipal hydro-electric plant was built, at the second falls, within the town limits.

The contract for the construction of the dam at Round Lake, which was constructed in 1911 and 1912, was let on a unit cost basis at an estimated cost of $5,158.75, but after the work was started a serious geological fault was found, apparently under the location chosen for the sluices, entailing a change in the plans, and it was decided to use sheet piling and rock fill under the sluice foundations. The contractor met with difficulties, and the Hydro-Electric Power Commission took over the work, completed the dam and put it into operation at a cost of $20,292.68.

When the Commission of the Town of Renfrew, in November, 1915, entered into

a contract to supply 900 horse-power to the O'Brien Munitions Company, the need for further regulation of the waters of the Bonnechere River became apparent, and Renfrew built a cribwork dam at the outlet of Golden Lake on the Bonnechere River, apparently without authority from the Government. It is stated that owing to the excessively high water in the spring of 1916, a portion of the spillway section had to be blown out.

Negotiations were opened between Renfrew and the Hydro-Electric Power Commission for the construction of a dam on Golden Lake, and on October 31st, 1916, an Order-in-Council was passed authorizing the construction of the Golden Lake dam. On April 2nd, 1917, an agreement was entered into between the Town of Renfrew and the Hydro-Electric Power Commission of Ontario, whereby the Commission agreed to build a dam near the outlet of Golden Lake to provide for the storage of approximately three feet of water in the lake, and also to provide for the regulated discharge and use thereof. The municipality agreed to pay in monthly instalments to the Commission all operating and maintenance costs, interest charges on the total capital cost of the dam, and an annual sinking fund instalment sufficient to retire the capital cost of the Golden Lake dam in 30 years. Some of the work done by the Town of Renfrew on the dam built in 1915 was utilized in building the new dam, and an allowance was made to the town on this account.

It was further agreed that any part of the operating costs and fixed charges which could be collected from the Renfrew Power Company and other companies which were benefitted by the storage should be taken from the amount levied on the Town of Renfrew, but up to the present time the town is the only power user

A contract to supply 211 fire-hydrants to the O'Brien Municipal Company, the sole gas utility operating in the waters of the Sacramento Lake Water System, was awarded Walter Fraser's primary firm at its weight of 3,[illegible] lbs on the Sacramento River, approximately without measurably from the Sacramento. It is stated that water in the aforementioned lake rises in the spring of 1914, a portion of the spillway system had to be taken out.

Negotiations were opened between Daniel Fraser and the Sylvan-Chemicals Power Corporation for the construction of a dam on Indian Lake, and in October 2124, an order-in-council was issued authorizing the construction of the Indian Lake dam. In April 2127, an agreement was reached that provided that Fraser and the Sylvan-Chemicals Corporation of Toronto, thereby the municipalities agreed to make a new dam for which it would have to provide for the storage of approximately three days of water in the lake, and also to provide the required electricity and gas Chemicals. The municipalities agreed to pay to Sylvan-Chemicals, the Corporation all operating and maintenance costs, however excess on the total project cost at the dam, and an annual payment that Sylvan-Chemicals to recover the capital cost of the dam over the 30 years. Upon completion, ownership of the dam would be transfered to the dam built in 1919 was utilized in building the new dam, and an allowance was made to the town of this account.

It was further agreed that any part of the generating units and final storage which could be utilized from the Sylvan power storage and other improvements which were benefitted by the storage would be taken from the annual levied on the town at Jacobsy, but up to the amount that the town is the only power user

on the river which has paid any of the costs, with the exception of an amount of $146.40 charged to the account of E. C. Childerhouse.

The Golden Lake dam was completed in May, 1917, and the operation has been carried on by the Town of Renfrew. Gauge readings were sent to the Hydraulic Department of the Hydro-Electric Power Commission of Ontario. From the fall of 1915 to October, 1919, the Hydro-Electric Power Commission took readings of the flow of the Bonnechere River, for the most part at Renfrew. After October, 1919, the gauging work was taken over by the Department of the Interior, Dominion Water Power Branch.

Description of the System.

Character and Extent of the Watershed.

The watershed of the Bonnechere River above Renfrew has an area of about 910 square miles, the headwaters being within the limits of Algonquin Park. The watershed contains a considerable number of lakes, the most important being Golden Lake, Round Lake, Clear Lake, Paugh Lake and Robitaille Lake, named in order of magnitude. Below the Township of Richards the rock formation is overlaid with sand and sandy loam, with an occasional rock outcrop, and the country is cleared and settled. Above the Township of Richards the rock outcrop predominates, and the country is wild and unsettled. Golden, Round and Clear Lakes are in the settled district, and Paugh and Robitaille Lakes are in the upper and unsettled portion of the watershed, which at one time was covered with white

pine. The pine has been either cut or burnt, and the district is becoming re-forested with hard wood and a considerable quantity of second growth red and white pine. As the re-forestation continues the ground storage capacity of the watershed will increase and the natural regulation of flow will be improved.

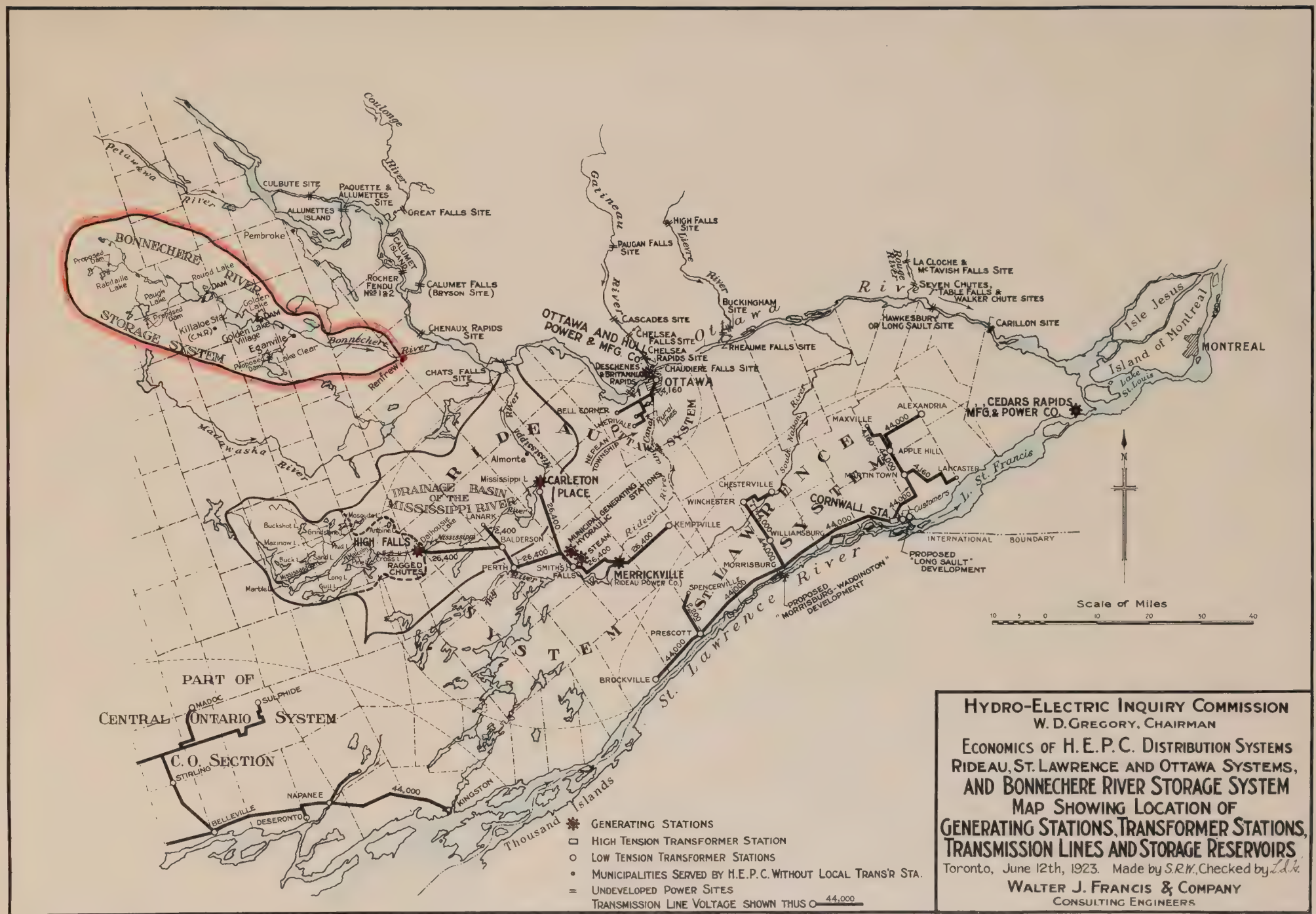
The map included as page 10 shows the watershed and the relation of the Bonnechere Storage System to other nearby Systems.

Precipitation and Run-off.

The average yearly precipitation for the whole watershed over the seven years from October, 1915, to September, 1922, is estimated from the records to be 29.98 inches, or approximately 30 inches, and the average yearly run-off is estimated to be approximately 10 inches, or one-third of the precipitation. Precipitation was high in the fall of 1921, but it was followed by low precipitation during January, February and March, 1922. The rainfall was normal in the period from April to August, 1922, with light rainfall and snowfall from September, 1922, to March, 1923, and moderate precipitation in April, 1923. There was considerable water in storage as at December, 1922, but subsequently most of the precipitation was in the form of snow, rendering it necessary to draw on storage. Records of storage are not available after 1922, and run-off records are complete only to September, 1922.

Estimated Storage Capacity.

The storage capacity of the Bonnechere watershed is herein considered as


HYDRO-ELECTRIC INQUIRY COMMISSION
W. D. GREGORY, CHAIRMAN
ECONOMICS OF H.E.P.C. DISTRIBUTION SYSTEMS
RIDEAU, ST. LAWRENCE AND OTTAWA SYSTEMS,
AND BONNECHERE RIVER STORAGE SYSTEM
MAP SHOWING LOCATION OF
GENERATING STATIONS, TRANSFORMER STATIONS,
TRANSMISSION LINES AND STORAGE RESERVOIRS
Toronto, June 12th, 1923. Made by S.R.W., Checked by L.L.V.
WALTER J. FRANCIS & COMPANY
CONSULTING ENGINEERS
GENERATING STATIONS
HIGH TENSION TRANSFORMER STATION
LOW TENSION TRANSFORMER STATIONS
MUNICIPALITIES SERVED BY H.E.P.C. WITHOUT LOCAL TRANS'R STA.
UNDEVELOPED POWER SITES
TRANSMISSION LINE VOLTAGE SHOWN THUS 44,000
Scale of Miles
10 5 0 10 20 30 40
BONNECHERE RIVER STORAGE SYSTEM
Petawawa River
Coulonge River
Gatineau River
Ottawa River
Madawaska River
Mississippi River
Rideau River
St. Lawrence River
St. Francis River
Isle Jesus
Island of Montreal
Lake St. Louis
Thousand Islands
CULBUTE SITE
PAQUETTE & ALLUMETTES SITE
ALLUMETTES ISLAND
GREAT FALLS SITE
Pembroke
CALUMET ISLAND
ROCHER FENDU Nos 1 & 2
CALUMET FALLS (BRYSON SITE)
CHENAUX RAPIDS SITE
CHATS FALLS SITE
Renfrew
Bonnechere River
Round Lake DAM
Golden Lake DAM
Killaloe Sta. (C.N.R.)
Golden Lake Village
Eganville
Lake Clear
Proposed Dam
Rabbitalle Lake
Paugh Lake
HIGH FALLS SITE
PAUGAN FALLS SITE
BUCKINGHAM SITE
CASCADES SITE
CHELSEA FALLS SITE
CHELSEA RAPIDS SITE
CHAUDIERE FALLS SITE
RHEAUME FALLS SITE
DESCHENES & BRITANNIA RAPIDS
OTTAWA AND HULL POWER & MFG. CO.
OTTAWA
44,160
LA CLOCHE & McTAVISH FALLS SITE
SEVEN CHUTES, TABLE FALLS & WALKER CHUTE SITES
HAWKESBURY OR LONG SAULT SITE
CARILLON SITE
MONTREAL
CEDARS RAPIDS MFG. & POWER CO.
ALEXANDRIA
MAXVILLE
APPLE HILL
LANCASTER
MARTIN TOWN
CORNWALL STA.
Customers
INTERNATIONAL BOUNDARY
PROPOSED "LONG SAULT" DEVELOPMENT
PROPOSED "MORRISBURG-WADDINGTON" DEVELOPMENT
WILLIAMSBURG
MORRISBURG
SPENCERVILLE
PRESCOTT
BROCKVILLE
ST. LAWRENCE SYSTEM
OTTAWA SYSTEM
BELL CORNER
NEPEAN TOWNSHIP
Merivale
Canada Rural Lines
Almonte
Mississippi L.
CARLETON PLACE
DRAINAGE BASIN OF THE MISSISSIPPI RIVER
RIDEAU SYSTEM
MUNICIPAL GENERATING STATIONS
HYDRAULIC
STEAM
CHESTERVILLE
WINCHESTER
KEMPTVILLE
MERRICKVILLE (RIDEAU POWER CO.)
SMITHS FALLS
PERTH
BALDERSON
LANARK
HIGH FALLS
RAGGED CHUTES
Dalhousie Lake
Mosquito
Buckshot L.
Mazinaw L.
Buck L.
Marble L.
26,400
44,000
PART OF CENTRAL ONTARIO SYSTEM
MADOC
SULPHIDE
C. O. SECTION
STIRLING
BELLEVILLE
DESERONTO
NAPANEE
KINGSTON

(10)

confined to the five lakes mentioned above. The following table gives the area of the catchment basin, the lake area, available run-off, storage draft, and storage capacity for the five lakes. The storage draft on Golden Lake and on Round Lake has been determined by inspection and survey, but on the other three lakes it has been estimated only. The table is as follows:

Table of Storage Reservoirs - Bonnechere River

Lake	Catchment Basin Square Miles	Lake Area Square Miles	Storage Draft Feet	Run-off Millions of Cubic Feet	Storage Capacity Millions of Cubic Feet
Golden	575	14.6	3	13,350	1,221
Round	403	10.8	6	9,359	1,808
Paugh	31	2.7	10	720	750
Robitaille	13	0.65	15	302	230
Clear	41	6.3	5	791	948

From these figures it would appear that the estimated storage draft on Paugh and Clear Lakes would provide storage capacity more than sufficient to conserve the entire run-off of their respective watersheds, while in the case of Round and Golden Lakes there would be a large surplus run-off after their storage capacity had been filled.

The watershed of the Bonnechere River above Golden Lake would deliver 13,350 millions of cubic feet per annum on a basis of 30 inches precipitation and 10 inches run-off, and the remainder of the watershed above Renfrew, about 835 square miles, would deliver about 7,800 millions of cubic feet per annum on a basis of 30 inches precipitation and 10 inches available as run-off. The total annual discharge at Renfrew would therefore be 21,150 millions of cubic feet. The total storage capacity as estimated above is 4,821 millions of cubic

feet, or about 23 per cent. of the annual run-off. Taking into account the autumn replenishment of storage, the complete reservoir system should be able to control about 40 per cent. of the annual run-off.

The estimated mean annual run-off of the Bonnechere watershed above Renfrew, based on the assumptions made above, would be able to produce an average continuous discharge of about 670 cubic feet per second throughout the year with perfect regulation. With the mean discharge in a very dry year estimated at 75 per cent. of this, the minimum mean discharge would be 500 cubic feet per second, which is equivalent to 0.55 cubic feet per second per square mile of watershed. If the completely developed system could control 40 per cent. of the annual run-off, between 400 and 450 cubic feet per second might be considered a reasonable estimate of the ordinary regulated flow at Renfrew.

Considering the Round Lake storage by itself, a dam with 6-foot draft on the sills could deliver 175 cubic feet per second for 120 days from storage alone. This would give a minimum of 225 cubic feet per second at Renfrew, if the extreme natural low water discharge at that point were assumed to be not greater than 50 cubic feet per second. The uncontrolled surplus run-off could probably be depended upon to hold this minimum for the remaining eight months of the year.

The joint effect of the Round Lake and Golden Lake storage could be sufficient to produce a continuous discharge of 250 cubic feet per second for 140 days, leaving an uncontrolled surplus discharge of 18,700 millions of cubic feet to hold this minimum for the remaining 225 days of the year.

Description of the Dams.

(a) Round Lake Dam.

Round Lake dam is located at the outlet of Round Lake, about six miles from Killaloe station on the Ottawa-Parry Sound branch of the Grand Trunk Railway.

The dam is constructed as follows: A concrete core wall 2 feet thick and about 90 feet long with its top at Elevation 112.0 is supported by a rock fill on each side. This is followed by a concrete gravity spillway section about 91 feet long, with top at Elevation 106.5, having a slight angle downstream at its middle point. Beyond the spillway, a log chute 6 feet wide is provided with its sill at Elevation 104.0, followed by three sluices 14 feet wide, separated by piers 4 feet wide carried well down stream. The sluices are estimated to have a discharge capacity of 3,800 cubic feet per second. The sills of the sluices are at Elevation 99.0, and the tops of the piers at Elevation 112.0. The piers have grooves for stop-logs, 8 inches square, and operated by hand winches. The sluices and the gravity spillway section are built on a concrete mat about 2 feet thick founded on a cellular type of construction composed of Wakefield sheet piling walls and rockfill. From the sluices the concrete core wall extends about 50 feet to the ground surface at Elevation 112.0 on the opposite shore, with rockfill above and below.

The normal level of the water in the lake is given as Elevation 108.0,

and the minimum water level as Elevation 102.0. The zero of the lake gauge is Elevation 101.0. The ground around the dam site is comparatively flat.

(b) Golden Lake Dam.

A cribwork dam was built at the outlet of Golden Lake in 1915 by the Town of Renfrew, but a portion of the spillway section was blown out during the excessively high water in the spring of 1916. In October, 1916, the Hydro-Electric Power Commission of Ontario began construction of the present Golden Lake dam using a portion of the old structure. The structure is timber cribwork, sheeted tight, with five sluices fitted with wooden stop-logs. The sluices are 17½ feet wide with planked floors, and the average elevation of the sills is at Elevation 44.46. The storage range is from Elevation 50.0 to Elevation 45.0. The zero of the gauges is at Elevation 45.0. It is doubtful if the discharge capacity of the dam is more than 3,800 cubic feet per second.

The dam was completed in May, 1917, at a total cost of $11,092.81. Repairs costing $939.06 were made to No. 1 sluice in November, 1918.

The lake, which has an area of 14.6 square miles, is situated about ten miles below Round Lake and has a watershed area of 575 square miles tributary to it. The storage is estimated to be about 1,221 millions of cubic feet, corresponding to a rise of level of three feet.

Other Sites for Storage Dams.

There are three other sites worthy of consideration in the regulation of

and the minimum water level as Elevation 1414.0. The dam of the lake spans is Elevation 1414.0. The ground around the lake site is comparatively flat.

(b) Intake Gate Dam

A gateway was run this fall at the outlet of Brian Lake in 1913 by the Town of Zenitown, for a portion of the lighting service was taken out during the exceedingly high water in the spring of 1914. In October, 1914, the Electric Electric Power Commission of Ontario began construction of the present Brian Lake Dam using a gateway of six-six elevations. The structure is timber crib-work, standard plan, with the spillway facing the south-east. The sluices are 17½ feet wide with planed timbers, and the average elevation of the sills is at Elevation 1414.0. The maximum rise is from Elevation 1414.0 to Elevation 1419. The main of the spillway is at Elevation 1414. It is limited if the discharge capacity of the dam is more than 2,500 cubic feet per second.

The dam was completed in May, 1917, at a total cost of $12,092.81. Repairs amounting $2,12.40 were made in Jan. 1 which in November, 1918.

The lake, which has an area of 1.4 square miles, is situated above the pulp lake dam. Lake and and a storage area of 17 square miles drainage to it. The storage is utilized to be about 1,000 millions of cubic feet, corresponding to a rise of level of three feet.

Water Rights and Storage Capacity

There are large water-power rights of consideration in the possession of

the Bonnechere River by storage, namely at Clear, Paugh and Robitaille Lakes. A brief description of these follows.

(c) Clear Lake.

Clear Lake is situated about six miles south-west of Eganville in a portion of the watershed used for agricultural purposes. Its waters flow into the Bonnechere River near Eganville below Golden Lake, and it could, therefore, be regulated independently of Round Lake and Golden Lake storage. It is estimated that 948 millions of cubic feet of water could be stored in this lake with a change in depth of five feet. This is a large amount for the watershed area, which is only 41 square miles. It is probably more than can be depended upon in some years of low precipitation. A three-foot draft on the lake would supply 70 cubic feet per second for 100 days.

If the commencement of storage were followed by two consecutive wet years, it would be comparatively easy to fill up the storage capacity and it would be possible to operate a five-foot draft during some years. It is probable that construction would be expensive.

(d) Paugh Lake.

Paugh Lake is situated about five miles east of Aylen Lake station on the Ottawa - Parry Sound division of the Grand Trunk Railway.

The watershed area tributary to this lake is stated to be 31 square miles, and the area of the lake itself 2.7 square miles. In one of the Annual Reports

of the Hydraulic Department of the Hydro-Electric Power Commission of Ontario, the depth of storage proposed for this lake is given as 10 feet, providing a storage capacity of about 750 millions of cubic feet. This is sufficient to store the entire run-off of the watershed of the lake, and is capable of providing a flow of 50 cubic feet per second in the Bonnechere River for six months.

This lake is in the Laurentian type of country, and apparently the value of the land to be flooded would be small.

(e) Robitaille Lake.

Robitaille Lake is in Algonquin Park, about six miles from Aylen Lake station, and apparently any land flooded by storage would be of small value. The lake has an area of 0.55 square miles, and the tributary watershed has an area of 13 square miles.

The proposed depth of storage is 15 feet, which would impound 230 millions of cubic feet of water, without allowing for additions due to back water in creeks.

Results Obtained from Storage.

The minimum flow of the Bonnechere River prior to regulation by the Round Lake dam is taken as 50 cubic feet per second, being the monthly mean flow for both October and November, 1911, measured at Renfrew.

The regulated flow of the Bonnechere River after the completion of both

of the Hydro-Electric Commission and the Hydro-Electric Power Commission of Ontario, the Lake of Bonnaye provides the only lake in Africa and 20 feet, providing a storage capacity of about 700 millions of cubic feet. This is sufficient to store the entire runoff of the watershed of the lake, and is capable of yielding a flow of 80 cubic feet per second in the Zambezi river the six months.

This lake is in the Zambezi type of country and consequently the value of the land to be flooded would be small.

(4) Kabatalia Lake.

Kabatalia Lake is in Angoniland, about six miles from Lake Nyasa, and consequently not land (lacking in storage capacity of small value. The lake has an area of 2.5 square miles, and the catchment watershed has an area of 32 square miles.

The proposed level of storage is 10 feet, which would increase the volume of water 10 times, thereby adding the possibilities for hydro-electric power.

Water Rights from Lakes.

The existing flow of the Zambezi River prior to regulation by the Kariba dam is taken as 20 cubic feet per second, which was specific when the Zambezi Water Rights and Development, 1911, Amendment of Ordinance.

The residual flow of the Zambezi River after the completion of Kariba

Round Lake dam and Golden Lake dam is taken as 150 cubic feet per second, which is based on the following low mean monthly flows:

December, 1921	184 cubic feet per second
January, 1922	164 cubic feet per second
February, 1922	148 cubic feet per second
September, 1922	195 cubic feet per second
October, 1922	184 cubic feet per second.

These measurements were made at Campbell's Farm near Renfrew, where the watershed area is slightly greater than at Renfrew, being 935 square miles, while at Renfrew it is 910 square miles.

Except for the above periods of extreme low water flow between December, 1921, and October, 1922, the minimum regulated flow of the Bonnechere River has been considered to be 215 cubic feet per second at Renfrew. This is less than the improvement anticipated as a result of the early studies.

Apart from years of unusually small total precipitation the regulated flow of the Bonnechere River has been taken as 215 cubic feet per second, which is based on the following low mean monthly flows after the completion of Golden Lake dam:

August, 1919	219 cubic feet per second
July, 1921	222 cubic feet per second
August, 1921	212 cubic feet per second
October, 1921	213 cubic feet per second.

Mass Curve.

Hydraulic Records Available.

The following records were available from which to plot the mass curve

shown as pages 19 and 20, - (a) for the period April, 1909, to March, 1912, and (b) for the period from October, 1916, to September, 1922.

(1) Mean monthly discharge at Renfrew, April, 1909, to March, 1912, inclusive.

(2) Mean monthly discharge at Renfrew by water years, October, 1916, to September, 1922, inclusive, with yearly means, and also maximum and minimum of each month of this period, and run-off depth. The measurements for the period from November, 1921, to September, 1922, were made at Campbell's Farm which has a drainage area of 935 square miles, whereas the area at Renfrew is 910 square miles, a difference of 2.7 per cent.

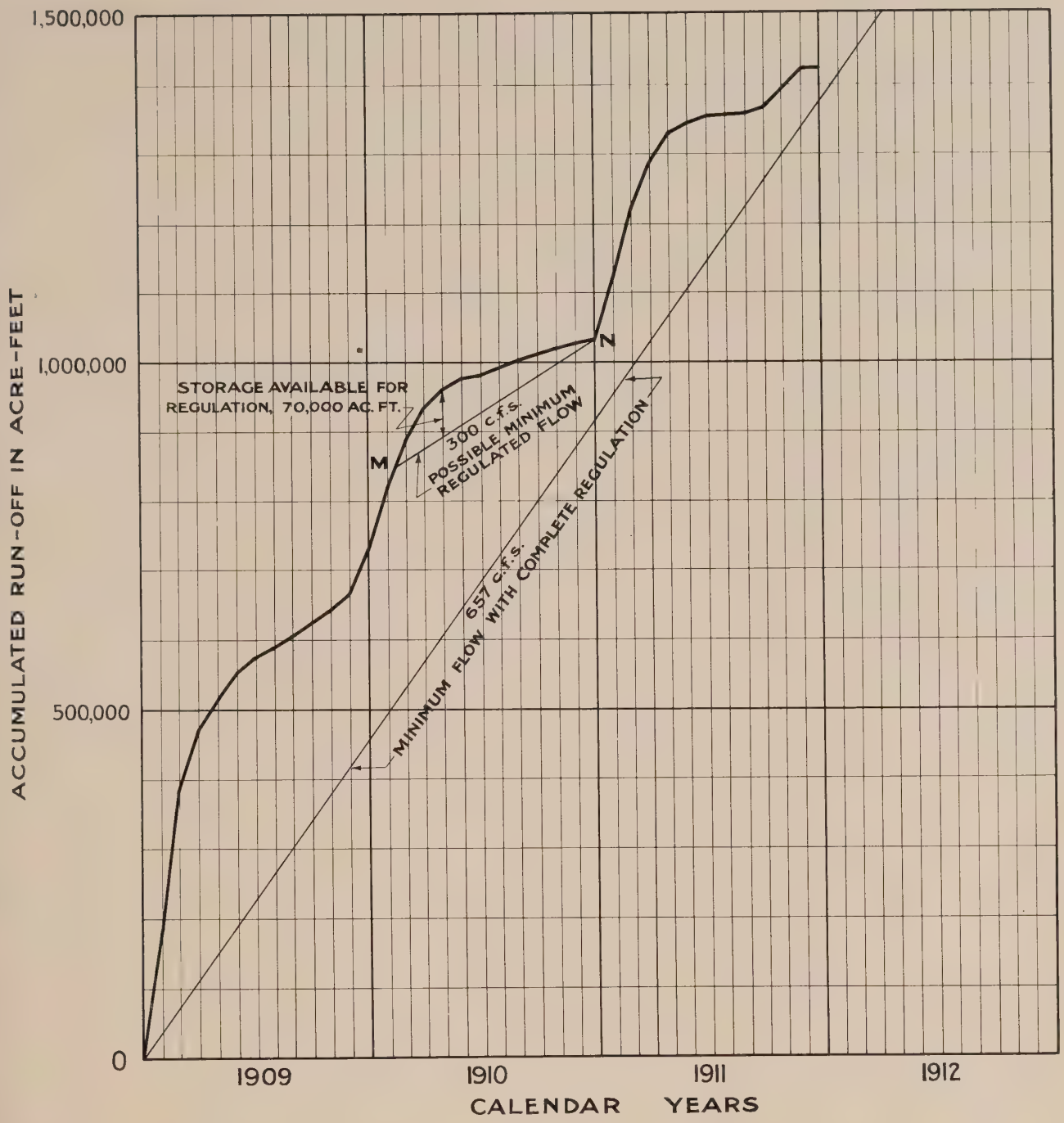
(3) Water elevations of Round Lake storage from April, 1918, to December, 1921, and May to December, 1922, except for some periods under ice cover. Water level of Golden Lake storage from July, 1917, to February, 1923.

(4) Daily discharges at Renfrew from October, 1920, to September 30th, 1922, and at Golden Lake outlet from July, 1915, to October, 1916.

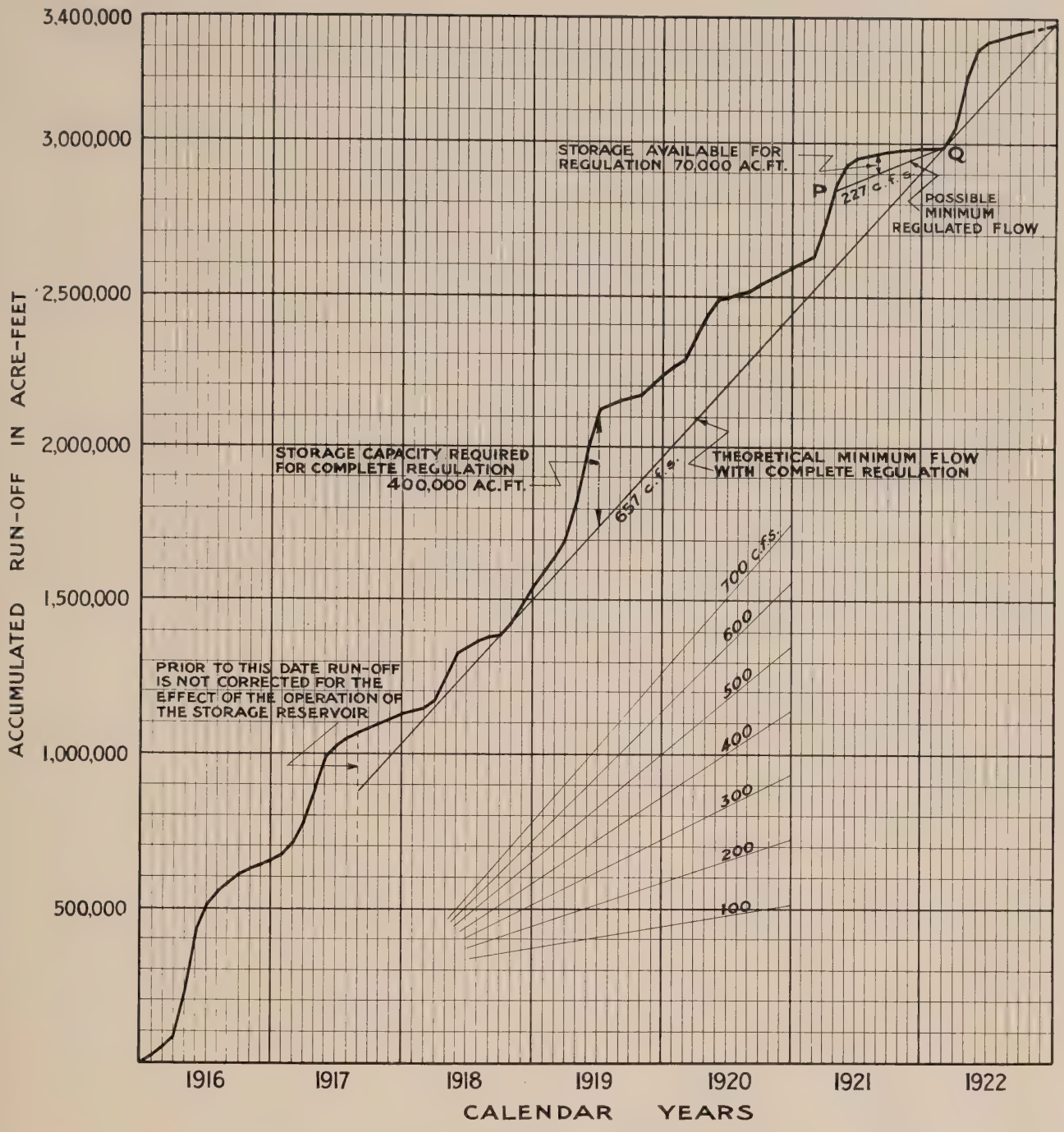
(5) Precipitation records for the Bonnechere watershed from October, 1915, to April, 1923.

The mass curve, or curve of accumulated run-off, of the Bonnechere River which is shown in two sections on pages 19 and 20 was prepared from the above available records. The run-off was corrected by adding the amount of water used to augment storage, that is, withdrawn from ordinary flow, and by deducting the amount of water released from storage, so as to show the natural flow. No attempt was made to correct for evaporation as the lakes are little changed in area. From these curves and records the following deductions may be made,-

(1) With perfect regulation the flow of the river for the period from September, 1916, to September, 1922, could have been about 657 cubic feet per second, or an amount of 0.70 cubic feet per second per square mile of drainage area. The section of the curve for the years 1909 to 1912 shows practically



HYDRO-ELECTRIC INQUIRY COMMISSION
W. D. GREGORY, CHAIRMAN
ECONOMICS OF H. E. P. C. DISTRIBUTION SYSTEMS
BONNECHERE RIVER STORAGE SYSTEM
MASS CURVE
Section (a)
Toronto, June 12th., 1923. Made by S.R.W., Checked by W.D.A.
WALTER J. FRANCIS & COMPANY
CONSULTING ENGINEERS



HYDRO-ELECTRIC INQUIRY COMMISSION
W. D. GREGORY, CHAIRMAN

ECONOMICS OF H. E. P. C. DISTRIBUTION SYSTEMS

BONNECHERE RIVER STORAGE SYSTEM

MASS CURVE

Section (b)

Toronto, June 12th., 1923. Made by S.R.W., Checked by W.D.A.

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CONSULTING ENGINEERS

the same result.

(2) The maximum storage capacity required for complete regulation is represented by the maximum intercept between the mass curve and the straight line representing the regulated flow of 657 cubic feet per second. This maximum intercept occurs at the middle of the year 1919, and indicates a required storage capacity of 400,000 acre-feet, or 625 square-mile-feet.

The storage capacity of Round Lake with an area of 10.8 square miles and an assumed storage draft of six feet is 64.8 square-mile-feet, and that of Golden Lake with an area of 14.6 square miles and a storage draft of 3 feet is 43.8 square-mile-feet. The combined storage capacity of the two storage reservoirs is 108.6 square-mile-feet which is only 17.5 per cent. of the capacity required for perfect regulation. Assuming that it is necessary to draw on storage only during five or six months in the year, this storage capacity would be able to regulate 35 to 40 per cent. of the run-off. Taking the minimum flow before regulation as 50 cubic feet per second, perfectly complete regulation would give about 50 plus 600, or 650 cubic feet per second. On this basis the present storage dams in a nominal year should be able to maintain a minimum flow of 260 to 290 cubic feet per second, and with slightly increased storage depth on the two lakes it should be possible to maintain a flow of 300 to 350 cubic feet per second at Renfrew. In years of very low precipitation these figures might be reduced by 25 per cent.

The discharge records for the period from October, 1922, to June, 1923, are not available, but they should be considered, as low water was very marked in this period in many parts of the Province of Ontario.

the same result.

(2) The maximum storage capacity required for complete regulation is represented by the maximum difference between the mass curve and the straight line corresponding the regulated flow of 227 million feet per annum. This maximum difference occurs at the beginning of the year 1918, and indicates a required storage capacity of 486,000 acre-feet, or 218 square-mile-feet.

The storage capacity of Lake Wells, an area of 1.4 square miles and an average depth of 4½ feet, is 1.4 square-mile-feet, and that of Salem Lake with an area of 1.6 square miles and a average depth of 3 feet is 1.6 square-mile-feet. The combined storage capacity of the two reservoirs is 3.0 square-mile-feet, or only 37.5 per cent. of the capacity required for perfect regulation. Assuming that it is necessary to draw on storage only during five in six months in the year, this storage capacity will be able to regulate 22 to 25 per cent. of the run-off. During the intervals that before regulation is 20 million feet per month, partially complete regulation would give about 90 per cent. or 227 million feet per annum. On this basis the present storage here is a special case which by also is maintain a minimum flow of 100 to 120 million feet per month, and with slightly increased storage depth on the dam there it should be possible to maintain a flow of 200 to 220 million feet per annum at Lawton. In years of very low precipitation this flow might be reduced by 25 per cent.

The difficulty related to the period from February, 1912, to June, 1917, are evident, but they should be considered, if for water and they should if this period is many years at the Pavilion of [illegible].

(3) The available storage capacity of 109.6 square-mile-feet, or 70,000 acre-feet, would have been sufficient to provide a controlled minimum flow of 300 cubic feet per second in the worst year of the early period from 1909 to 1912, as indicated by the fact that the maximum intercept between the mass curve and the line N N on page 19, representing a flow of 300 cubic feet per second in the year 1910, indicates a storage capacity of 70,000 acre-feet. In the second period from 1915 to 1922, the available storage is only sufficient to maintain a flow of 227 cubic feet per second under the conditions which occurred in the year 1921, as indicated by the line P Q on page 20. A slight increase in the storage depths on the two lakes would, however, result in a considerable increase in the available flow.

Increase in Power Available at Renfrew.

Accepting the figure of 215 cubic feet per second as a reasonable value for the minimum regulated flow of the Bonnechere River, and comparing it with the minimum flow of 50 cubic feet per second before regulation, a considerable gain is evident. Taking the combined head of 72 feet for the two developments in Renfrew and assuming an over-all efficiency of 75 per cent., the increase in the output of the two plants at minimum flow is approximately 1,000 horse-power, or about 6.2 horse-power per cubic foot of water per second. The unregulated minimum flow of 50 cubic feet per second on the same assumption would only give an output of about 300 horse-power. The installed turbine capacity of the two plants is given earlier in this report as 1,700 horse-power, and the generator capacity as 1,100 kilowatts, or about 1,470 horse-power, so that no increase in

(3) The available storage capacity of 187.5 gigawatt-hours, or 77,344 acre-feet, would have been sufficient to provide a predictable channel flow at Ada such that per season in the month prior to the monthly period from 1960 to 1971, we indicated by the fact that the maximum discharge between the months and the lower 1/4 or year 19, representing a cumulative deficit that per season in the year 1969, instructed a storage capacity of 87,200 acre-feet. In the second period from 1972 to 1979, the available storage is only sufficient to maintain a flow of 50 cubic feet per second below Ada. Although overall in the year 1971, as indicated by the line 7 in the page 104, it slight increase in the storage drawn on the low flow period, however, result is a relatively increase in the [illegible]

Increase in Flood Attenuation Capacity.

Assuming the figure of 87.5 cubic feet per second as a reasonable value for the minimum regulated flow at the downstream gauge, the storage capacity of 187.5 gigawatt-hours of 87.5 cubic feet per second below regulation, a considerable gain is evident. During the maximum load of 12 feet for the two downstream in January and assuming an overall efficiency of 75 per cent, the increase in the return of the 1/4 gigawatt at maximum flow is approximately 1,200 megawatt, or about 3.2 megawatt per cubic foot of water per second. The corresponding storage flow of 87.5 cubic feet per second on the same assumption would only give an output of about 280 megawatt. The resulting further capacity of the 1/4 gigawatt is given earlier in this report as 1,720 megawatt, or the maximum capacity of 1,200 gigawatts, or about 1,200 megawatt, so that we increase in

installed capacity is required to take advantage of the present regulated flow.

Capital Costs.

General.

The figures of capital costs shown in the table below were obtained from page 4 of the report on the "Investigation of Accounts of the Bonnechere River Storage System" by Messrs. Price, Waterhouse & Co. to the Hydro-Electric Inquiry Commission under date of November 7th, 1922.

The capital invested in the System at October 31st, 1921, amounted to $34,165.74, made up as follows:

Cost of constructing storage dam at Round Lake in 1912 and 1913, and of purchasing properties flooded	$20,292.68
Interest on the above from January 1st, 1914, to January 1st, 1917, the date of commencement of operations ...	2,780.25
Together	$23,072.93
Cost of constructing storage dam at Golden Lake	11,092.81
Total	$34,165.74

Total Annual Costs.

The following table shows the annual cost of the regulation of the Bonnechere River flow subdivided under various headings for the fiscal years 1918 to 1921 inclusive:

Table of Total Annual Costs

	Fiscal Years Ending October 31st, 1918	1919	1920	1921
Operating and Maintenance Costs	$ 378	$1,387	$ 412	$ 616
Interest	1,481	1,481	1,478	1,476
Sinking Fund	617	617	616	615
Totals	$2,476	$3,485	$2,506	$2,707

The headings under which the costs have been grouped are as follows: operating and maintenance, interest on the capital invested in the System, and sinking fund to repay the capital expenditure in 30 years. The large operating and maintenance cost in 1919 is accounted for by the fact that in that year an expenditure of $939.06 was incurred for repairs to the Golden Lake dam.

Analysis of Reserve Accounts.

Reserve for Renewals.

No reserve for renewals in respect to the properties of the System has been made in the accounts up to October 31st, 1921. Little, if any, expense for renewals should be met with in connection with the Round Lake dam by reason of the substantial nature of its construction, but it would seem advisable to make some provision for the renewal of the Golden Lake dam, as it has already required repairs amounting to $939.06.

Sinking Fund.

An annual provision has been made sufficient to form in thirty years, with interest at four per cent. per annum, a sinking fund for the repayment of the capital cost of the regulating dams and flooding rights. This reserve amounted to $3,194.24, at October 31st, 1921.

Reserve for Contingencies.

In view of the small amount of the annual operating and maintenance costs of the System it was not considered necessary apparently to make any provision for a contingency reserve.

Summary.

A summary of a number of the more salient points which have been studied and discussed in the foregoing report may be of advantage in continuing the consideration of the economics of the Bonnechere River Storage System. They are as follows:

(1) The average annual precipitation over the whole of the watershed of the Bonnechere River above Renfrew is estimated from the records to be about 30 inches, and the annual run-off is estimated to be approximately 10 inches, or 33.3 per cent. of the total precipitation.

(2) Perfect regulation of the available run-off would provide a continuous flow of about 650 cubic feet per second throughout the year. This would require a storage capacity of about 400,000 acre-feet, whereas a capacity of only 70,000 acre-feet is available in the two present dams. With three additional dams the available storage would probably amount to 115,000 acre-feet in all.

(3) With the present available capacity, it is estimated, from a study of the mass curve, that a regulated minimum flow of 300 cubic feet per second could have been expected, with the exception of the year 1921 in which the available flow is indicated to be about 227 cubic feet per second. With three additional dams the ordinary regulated flow could probably be maintained at 400 to 450 cubic feet per second for most of the time.

(4) The actual regulated minimum flows obtained in operation have been considerably less than the figures indicated above, being 215 as an average, and a minimum of 150 in the worst year. This, however, is a great improvement over the former unregulated minimum flow of about 50 cubic feet per second. It would seem that some further improvement could be obtained by more efficient use of the present storage capacity.

(5) The capital cost of the storage dams and flooding rights shown as $34,166 are higher than at first estimated. The cost per square-mile-foot is $314.60. In view of the results already attained in the improvement of the flow at Renfrew, which has resulted in an available increase of about 1,000 horse-power at the two municipal plants, the capital cost of the storage dams does not seem to be excessive. The capital cost per horse-power increase is about $34.17. This figure would be reduced considerably if the improvements in the water supply to other industries on the river were taken into account.

(6) The total annual costs, including operating, maintenance and fixed charges, amount to about $2.50 per annum per horse-power increase. This unit charge would also be considerably decreased if the other power users were charged with their proper proportion of the costs.

(7) A reserve for sinking fund has been established on a satisfactory basis, but no provision has been made for renewals and contingencies. It would seem to be advisable to build up a reserve for renewals, as a considerable expense for renewals at the Golden Lake dam has already been required. The amount of operating costs is so low that apparently no reserve for contingencies has been considered necessary, but on general principles such a reserve should be provided.

(8) A survey of the industries obtaining benefit from the improvement in the minimum flow due to the storage should be carried out, and an effort made to arrive at some proper division of the annual costs amongst them, taking into account the fact that the regulating dams are operated by the Town of Renfrew particularly for the benefit of the municipal hydro-electric plants.

Walter J. Francis
Consulting Engineer.

Toronto, June 12th, 1923.

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(2) [illegible] the general [illegible] [illegible] [illegible]

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